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Basaltic volcanism and mass extinction at the Permo-Triassic boundary: Environmental impact and modeling of the global carbon cycle

A. Grard[a], L.M. François[a,c,*], C. Dessert[b,d], B. Dupré[b], Y. Goddéris[b]

[a]Laboratoire de Physique Atmosphérique et Planétaire, Université de Liège, Bât. B5c, 17 Allée du Six Août, B-4000 Liège, Belgium
[b]Laboratoire des Mécanismes de Transfert en Géologie, UMR 5563, CNRS-Université Paul Sabatier-IRD, Toulouse, France
[c]Centre de Recherches Pétrographiques et Géochimiques, CNRS, Vandoeuvre-lès-Nancy, France
[d]Department of Earth Sciences, University of Cambridge, Cambridge, UK

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Abstract

The Siberian Traps represent one of the most voluminous continental flood basalt provinces on Earth. The mass extinction at the end of the Permian was the most severe in the history of life. In the present paper, these two major concurrent events that occurred are analysed and a geochemical model coupled with an energy balance model is used to calculate their environmental impact on atmospheric CO_2, oceanic $\delta^{13}C$, and marine anoxia. The latitudinal temperature gradient is reduced relative to today, resulting in warmer temperatures at high latitudes. The warmer climate and the presence of fresh basaltic provinces increase the weatherability of the continental surfaces, resulting in an enhanced consumption of atmospheric CO_2 through weathering. First, the eruption of the Siberian traps is accompanied by a massive volume of ^{13}C depleted CO_2 degassed from the mantle and added to the ocean through silicate weathering, thus lowering marine $\delta^{13}C$. Second, the rapid collapse in productivity induces a strong decrease in the global organic carbon burial. This too tends to increase the proportion of light carbon in the ocean. These two effects can explain the low $\delta^{13}C$ values across the PT boundary, and methane release need not be invoked to explain the $\delta^{13}C$ fluctuations. It is proposed that the phosphorus cycle, which drives primary production in the model, plays an important role on the recovery of productivity and the $\delta^{13}C$ variations.

Keywords: Permo-Triassic boundary; carbon cycle; basaltic traps; extinction; modeling

1. Introduction

During the Late Permian, about 250 million years ago (Ma), the continents were aggregated into the supercontinent Pangea. The breakup of Pangea began

* Corresponding author. Tel.: +32 4 366 97 76; fax: +32 4 366 97 11.
E-mail address: francois@astro.ulg.ac.be (L.M. François).

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shortly after the emplacement of basaltic traps, which now cover vast areas of the Siberian platform. The original volume of basalt exceeded 2×10^6 km^3, and may have reached twice that amount [1], but only 4×10^5 km^3 currently remain. Kerrick [2] estimated a total volume of about 3.3×10^6 km^3, but many authors [3,4] assume that the area of the basaltic flows was about 1.5×10^6 km^2, although the present-day area of basalts is much smaller (3.4×10^5 km^2). According to Reichow et al. [5], the total area of the traps is at least doubled (and possibly more than tripled) by inclusion of the West Siberian Basin (WSB) basalts, giving a combined area of 3.9×10^6 km^2 and making the Siberian flood basalt province the largest subaerial volcanic event in the Phanerozoic record. Claoué-Long et al. [6] obtained U–Pb dates of zircons from an ash band immediately below the PT boundary in Southern China of 251.2 ± 3.4 Ma. Renne et al. [7] analysed sanidine from the same ash band and obtained an ^{40}Ar–^{39}Ar age of 249.91 ± 1.52 Ma. Redating the same ash band again, Bowring et al. [8] obtained a U–Pb age of 251.4 ± 0.3 Ma. These dates suggest the PT boundary occurred between 250 and 251 Ma, with a greater likelihood for the older end of this age range. More recently, Mundil et al. [9] concluded that the PT boundary must be slightly older than 252.5 ± 0.3 Ma. The radiometric dating efforts suggest that the onset of eruptions was coincident with the PT boundary within a few hundreds of thousands of years. Estimates for the duration of volcanism range from 0.6 [10] to 1 million years [7].

During the end Permian mass extinction, it is estimated that 96% of marine species [11] and 70% of terrestrial vertebrate families went extinct [7]. Land plants were also affected. The causes of this catastrophic event are currently a topic of intense debate. Many processes have been offered to explain the biological extinction, including changes in sea level, climate change, large-scale volcanism, overturn of the ocean with the release of toxic gases, massive methane release from methane hydrates, a bolide impact, and others [12]. However, confusion remains in regard to whether geochemical signatures at the PT boundary reflect the causes or the effects of the extinction. For example, the release of isotopically light carbon into the atmosphere by volcanism induces a drop in the carbon isotopic composition (δ^{13}C) of the oceans, but this drop could also have been generated by a sudden mass extinction. In any case, given the coincidence between Siberian Trap emplacement and the PT boundary, it seems likely that volcanism at least contributed to the extinction [1,7,8].

Jin et al. [13] suggest that the peak in extinction rates occurred at 251.4 Ma, followed by the gradual disappearance of a small number of surviving genera over the next million years. The rapid marine extinction in the Meishan sections of Southern China coincides with the dramatic shift in the δ^{13}C composition of seawater (Fig. 1). According to Bowring et al. [8], the age of the event boundary is also 251.4 ± 0.3 Ma at Meishan, and the biostratigraphically defined PT boundary is $< 251.4\pm0.3$ Ma and $> 250.7\pm0.3$ Ma. Their geochronological data indicate that the main pulse of Changhsingian

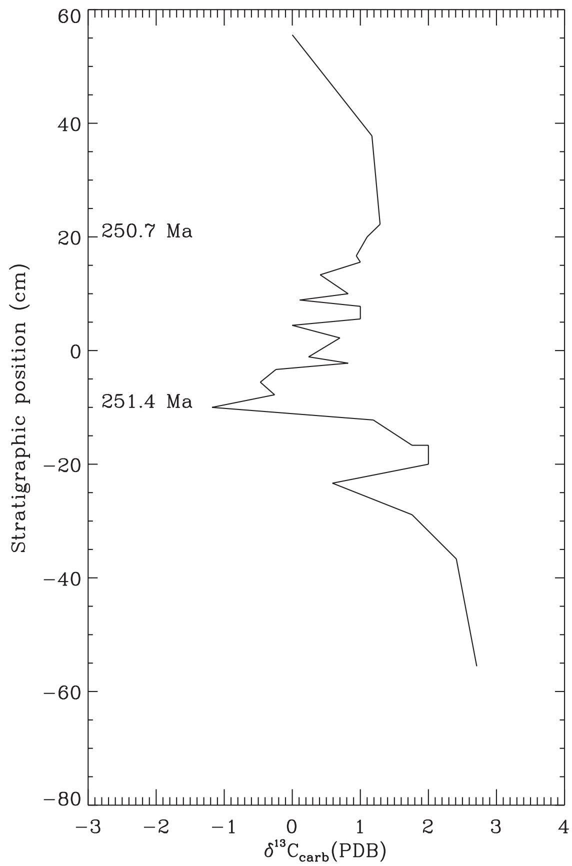

Fig. 1. Carbon isotope profile of PT boundary interval at section B of Meishan, China. Horizontal scale is δ^{13}C in ‰; numbers on the right-hand side are ages in million years. After Jin et al. [13].